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RESEARCH

3D Printing of Unconventional Starches from Andean Tubers: Microstructural, Textural, and Rheological Properties

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Abstract

This study evaluated the potential of unconventional starches extracted from Andean tubers, ulluco (Ullucus tuberosus) and cubio (Tropaeolum tuberosum), as raw materials for 3D food printing. Gels were formulated with starch concentrations of 8%, 10%, and 12% (w/v) and characterized in terms of microstructure and rheological properties. Both starches exhibited suitable printability, attributed to their pseudoplastic flow behavior. However, the hardness of the printed structures varied depending on starch type and concentration. Cubio starch showed higher hardness at both low and high concentrations (8% and 12%), whereas ulluco starch exhibited its highest hardness at the lowest concentration. Microscopic analysis revealed reticulated networks whose homogeneity was influenced by the degree of gelatinization and the starch content in the matrix. The printed gels demonstrated good resilience, variable hardness, and low crystallinity, indicating thermal-induced disruption of the native ordered structure. Rheologically, the samples showed viscoelastic behavior dominated by the elastic modulus (G') and fitted the power-law model. These findings support the technological feasibility of ulluco and cubio starches as functional ingredients for the development of customized or functional foods through additive manufacturing technologies. Their application may foster the utilization of underused crops and contribute to the diversification of raw materials in the food industry.

Keywords Printability · Gelatinization · Non-conventional starches

Introduction

Three-dimensional (3D) printing is an emerging technology that produces physical structures by depositing a material or a material blend layer by layer, resulting in a product with predetermined size and shape characteristics [1, 2]. This technology offers various production advantages for the food industry, including product customization in shape, size, sensory and nutritional properties; optimization and automation; waste reduction; and cost-effectiveness improvement [3, 4]. For instance, Kim et al. [5]. designed a low-calorie formulation to produce surimi by 3D printing with a protein analog, obtaining texture and salinity characteristics similar to those of commercial surimi. Similarly, Bebek et al. [6]. produced 3D printed snacks from strawberry products with antioxidant and antimicrobial potential, meeting nutritional needs and ensuring stability of the printed food during storage.

However, 3D food printing requires, during the design process of food inks, the incorporation of raw materials that meet specific nutritional requirements such as proteins, vitamins, and others, as well as additional components that not only provide nutritional value but also contribute to the structural properties of the product. This is essential to ensure the physical integrity of the printed food and to prevent its collapse during production, transportation, and storage [7]. Consequently, the materials used for this purpose (structural integrity) must have malleability, self-support, rapid solidification, and a specific level of fluidity that can generate a smooth extrusion from the printer's extrusion

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